TECHNICAL BULLETIN

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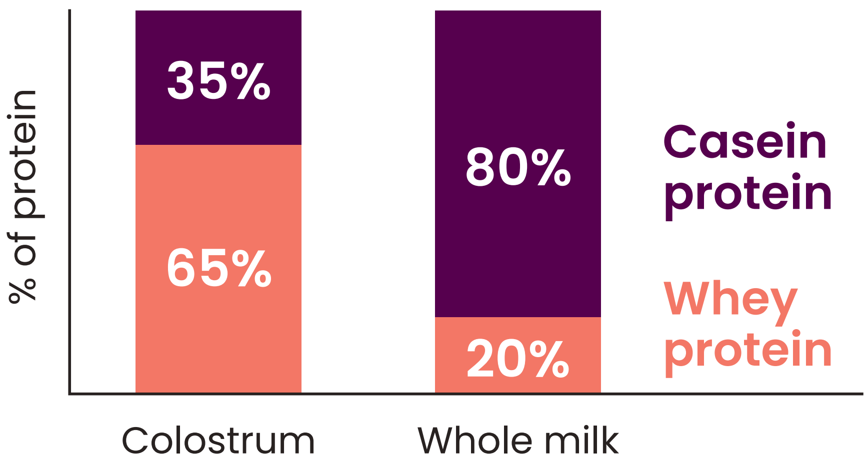
Dairy Protein in Calf Milk Formulas - Skim vs. Whey

Dairy ingredients are the main source of protein in milk replacers and these include both skim and whey protein. When processed under carefully controlled conditions, both skim and whey-based milk replacers can result in similar levels of calf performance. Calf performance is however, linked to more than just the type of dairy protein in the finished milk formula – the type and quality of all the ingredients and the processing conditions, which influence overall digestibility, are key.

Origins of Dairy Products

The proteins which make up whole milk may, in simple terms, be differentiated into casein and whey; casein makes up 80% of the protein and the balance consists of albumins and globulins (whey protein, 20%). Whey proteins include β-lactoglobulin, α-lactalbumin, immunoglobulins, bovine serum albumin, bovine lactoferrin and lactoperoxidase, together with other minor components. The albumins and globulins (including immunoglobulins) which make up whey protein in whole milk have a high biological value – they are essential in supporting the immune system and influencing the growth and development of the calf. Colostrum contains three times more whey protein (which makes up 65% of the protein content, with only 35% casein) than whole milk (Figure 1). The reason why there is so much more whey in colostrum than in whole milk is because the whey fraction contains the beneficial ingredients that are essential for calf health, growth and development.

Figure 1. Protein composition of colostrum & whole milk (source: Volac)



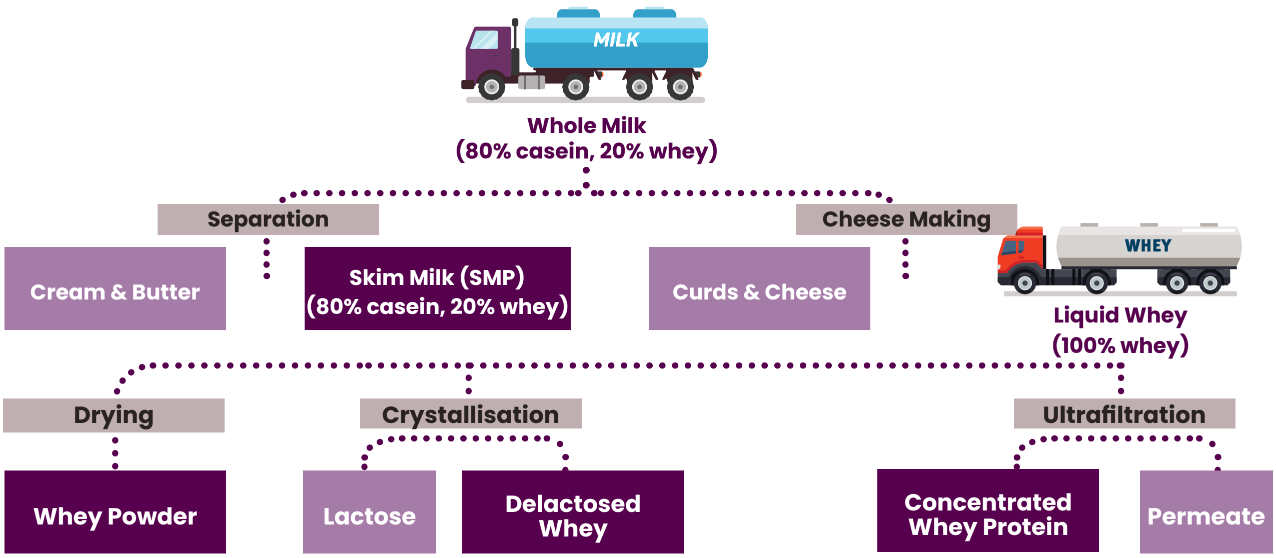
COLOSTRUM: CONTAINS 3x MORE WHEY PROTEIN CONTENT vs WHOLE MILK.

WHEY - CONTAINS THE BIOACTIVE CONTENT FOR CALF SUCCESS.

Skim Milk & Whey Protein:

Skim and whey are both produced as co-products of dairy products destined for the human food industry (butter and cheese). Skim milk powder is simply whole milk with the fat removed, and contains 80% casein, 20% whey. Whey protein is a co-product of cheese production - liquid whey is defined as the liquid fraction remaining after the precipitation of caseins (Figure 2).

Figure 2. Origin of dairy products used in milk formulas (source: Volac)



There are different methods to process liquid whey, resulting in various types of whey including whey powder, delactosed whey and concentrated whey protein. The different types of whey range in both protein and lactose content (Table 1). For example, whey powder contains 12.5 to 13% protein, compared to concentrated whey protein which typically contains 35% protein. Thus, whey powder in a finished milk formula will not contribute the same level of dairy protein as a milk formula containing concentrated whey protein.

Table 1. Typical analysis of dairy products used in milk formulas (source: Volac)

	Dried skim milk	Whey powder	Delactosed whey	Concentrated whey protein
Protein, %	35	12.5-13	27	35
Oil, %	1	1	1	5.5
Lactose, %	52	73	49	48
Ash, %	7	7	17	6

Nutrition of the Calf

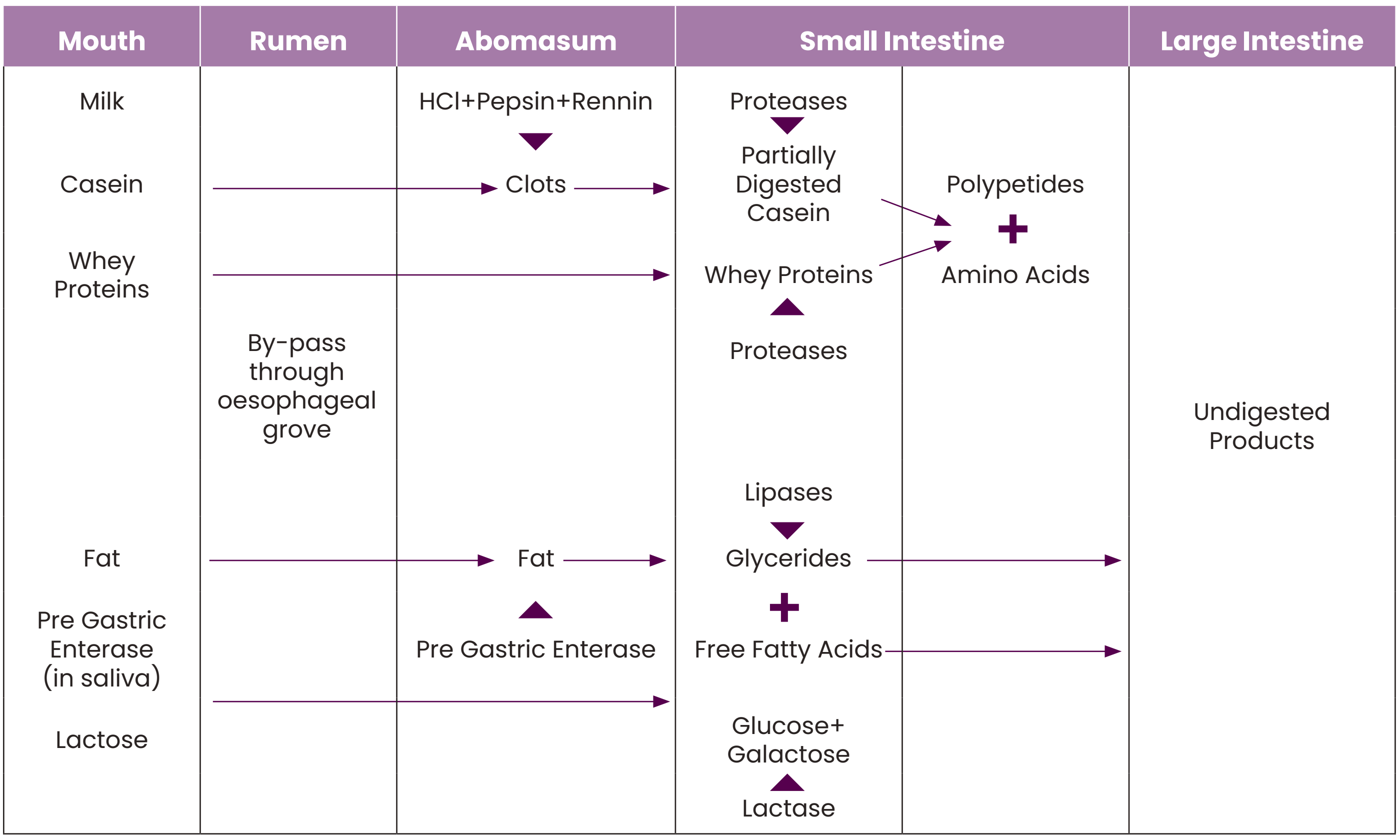
The calf functions similarly as a monogastric animal for approximately the first 2 to 3 weeks, and the abomasum is where the main digestive processes begin. The calf depends on milk or milk replacer as an easily digestible source of carbohydrate and protein. For the first three to four weeks of life, the enzyme lactase predominates, meaning the calf can effectively utilise lactose[1], the major carbohydrate in milk.

When whole milk enters the abomasum, via the oesophageal groove, a clot is formed within 10 minutes of feeding, as a result of the enzymes rennin and pepsin, and hydrochloric acid in the abomasum acting upon the casein protein in digesta[2] (Figure 3). Rennin binds with casein protein, and the clot is slowly digested, and emptied from the abomasum into the small intestine for up to approximately 24 hours[2]. The whey proteins and lactose, initially trapped within the casein clot, are released and pass quickly through the abomasum into the duodenum for further digestion[2]. In the small intestine, whey proteins and polypeptides (arising from the partial digestion of casein) are digested by the pancreatic enzymes (proteases). Lactose is broken down by the enzyme lactase in the duodenum, releasing glucose and galactose and these are absorbed providing an immediate (and major) energy source for young calves.

Milk Replacer

When whey is the only source of dairy protein in a milk formula, no clot will form within the abomasum, due to the absence of casein. The development of a firm abomasal clot in calves fed diets based on skim has previously been believed to benefit digestion because of the slow release of nutrients from the abomasum[3], but more recent research has shown that the clotting effect of casein is not required for optimal calf performance.

Figure 3. Nutrition of the calf



Dairy Protein & Digestibility:

Whilst rennin specifically breaks down casein protein, there are other mechanisms which enable the calf to digest and utilise whey proteins. Whey protein is naturally digested in the small intestine, by the pancreatic enzymes (proteases) without the action of abomasal proteases[4] (Figure 3).

The digestibility of milk replacers with dried skim milk (DSM) and / or whey protein concentrate (WPC) as the primary protein source has been assessed in Holstein bull calves from 12 to 36 h of age to 8 weeks of age (Table 2)[2]. Milk replacers were formulated to contain 100% DSM; 67% DSM + 33% WPC; 33% DSM + 67% WPC; or 100% WPC as the major milk protein source[2].

There were no significant differences in average daily gain and feed efficiency among the diets – all calves had similar rates of body weight gain up to 8 weeks[2]. Furthermore, the apparent digestibility of dry matter was not different among milk replacer diets (DSM and / or WPC) from weeks 2 to 8, demonstrating that whey protein concentrate is digested and utilised at least as well as skim milk protein by young calves (Table 2)[2].

Relatively low digestibility's of crude protein was expected initially because most calves scoured during week 2, although there was no difference in the incidence of scours between the treatment groups from week 1 to 8[2]. The mean number of days that calves scoured according to diet was 100% DSM, 3.5 days; 67% DSM + 33% WPC, 3.5 days; 33% DSM + 67% WPC, 4.0 days; and 100% WPC, 2.25 days[2].

Milk replacer diets varying in the ratio of dried skim milk to whey protein concentrate had no effect on the health, growth or apparent digestibility's in Holstein calves – therefore, dried skim milk and whey protein concentrate were comparable dairy protein sources for milk formulas for calves from 12 to 36 hours of age up to 8 weeks[2].

Table 2. Growth, feed efficiency & protein digestibility of calves fed milk replacers differing in sources of dairy protein (dried skim milk &/or whey protein concentrate) over 8 weeks[2]

	Milk replacer composition			
	100% Dried skim milk	67% DSM, 33% WPC	33% DSM, 67% WPC	100% Whey protein concentrate
Average daily gain, kg/d	0.39	0.36	0.37	0.39
Feed efficiency, kg of gain/ kg of DM	0.65	0.58	0.59	0.63
Apparent digestibility of crude protein, %				
Week 2	72.5	67.8	61.1	72.5
Week 4	77.2	83.2	83.5	83.9
Week 6	89.9	87.4	89.0	90.5
Week 8	90.0	91.5	89.4	88.4
Over all weeks, %	82.5	82.9	83.8	84.0

Milk replacer fed at 38.8 to 40°C twice daily at 10% BW 0-2 weeks, 12% initial BW 3-8 weeks.

Dairy Protein & Growth:

The effect of milk replacers containing whey protein concentrate, dried skim milk or combinations of WPC and DSM as the major protein source on growth rates, feed efficiencies, faecal scores and blood metabolites has been evaluated in Holstein calves from birth to 6 weeks of age[3]. Milk replacers were formulated to contain 100% DSM, 67% DSM + 33% WPC, 33% DSM + 67% WPC, or 100% WPC as the major milk protein source[3].

When only milk replacer was fed for 6 weeks (i.e. no starter was offered) higher proportions of whey protein concentrate in the milk formula improved calf performance (Table 3, trial 1)[3]. Calves fed milk replacer containing 67% WPC and 100% WPC had a higher average daily gain and a better feed conversion ratio than calves fed milk replacer containing 100% DSM (Table 3)[3].

When ad libitum starter was also provided, there were no apparent effects of dairy protein source of the milk replacer on calf growth and feed efficiency (Table 3, trial 2)[3]. There were also no differences in faecal score between the treatment groups in either trial (with or without starter) and blood haematocrit concentrations were not affected by milk replacer indicating that dairy protein source did not affect the degree of dehydration[3].

The performance of calves fed milk replacer with whey protein concentrate as the major dairy protein source was better than or equal to calves fed milk replacer containing 100% dried skim milk suggesting that the clotting effect of casein is not required for optimal calf performance[3].

Table 3. Intake, growth & feed efficiency of calves fed milk replacers differing in sources of dairy protein (dried skim milk &/or whey protein concentrate) from birth to 6 weeks of age[3]

	Milk replacer composition			
	100% Dried skim milk	67% DSM, 33% WPC	33% DSM, 67% WPC	100% Whey protein concentrate
Trial 1*:				
Milk dry matter intake, g/d	588	584	587	589
Average daily gain, g/d	199[b]	231[ab]	260[a]	258[ab]
Height, cm/d	0.11	0.13	0.13	0.14
Heart girth, cm/d	0.18	0.18	0.20	0.21
Feed efficiency, g of DM/g of gain	3.00[a]	2.52[ab]	2.29[b]	2.40[ab]
Trial 2+:				
Milk dry matter intake, g/d	590	587	583	580
Starter dry matter intake, g/d	399	437	406	390
Average daily gain, g/d	452	505	470	447
Height, cm/d	0.13	0.16	0.16	0.14
Heart girth, cm/d	0.22	0.24	0.24	0.23
Feed efficiency, g of DM/g of gain	2.21	2.01	2.43	2.16

*Trial 1: no starter. +Trial 2: ad lib starter (20.8% CP) provided from day 3. Milk replacer (22% CP, 18% fat) fed at 10% BW 0-2 weeks, 12% BW 3-6 weeks. Ad lib water available from day 3. [ab]Means in row with different superscripts were significantly different ($P<0.05$)

Dairy Protein & the High Milk Fed Calf

Previous research evaluating the effect of whey protein concentrate or dried skim milk as the major dairy protein source in milk formulas on calf performance has provided milk at levels in line with historical feed recommendations of 10 to 12.5% of body weight[2,3]. A recent Volac calf trial carried out at Hillsborough, Northern Ireland (2019), has evaluated calf performance when feeding calves at levels in line with current industry recommendations, of up to 7 litres of milk replacer per day (mixed at 150g per litre).

A total of 80 Holstein Friesian calves were fed milk replacer from birth to 56 days of age containing either 66% skim, 44% skim, 22% skim or 0% skim (0% = all whey protein concentrate). The source of the WPC used in the milk replacers was Volac Imunopro™ calf milk base.

There was no significant difference in body weight from birth to 70 days across treatments, with body weight ranging from 71.9 to 74.5 kg at weaning, and 86.3 to 89.4 kg on day 70 (Table 4, Figure 4). The average daily gain up to weaning was comparable across treatments between 0 and 14 days, and 14 and 56 days (Table 4). Similarly, average daily gain during the post weaning period was not related to the protein source of the milk replacer.

Calf health was comparable across treatments with no significant difference in the number of episodes of scour or respiratory illness between treatments (Table 4). Average faecal score was below 2 (faecal score, 1=normal consistency; 2=slightly liquid; 3=moderately liquid; and 4=primarily liquid) throughout the experimental period and was not affected by dietary treatment.

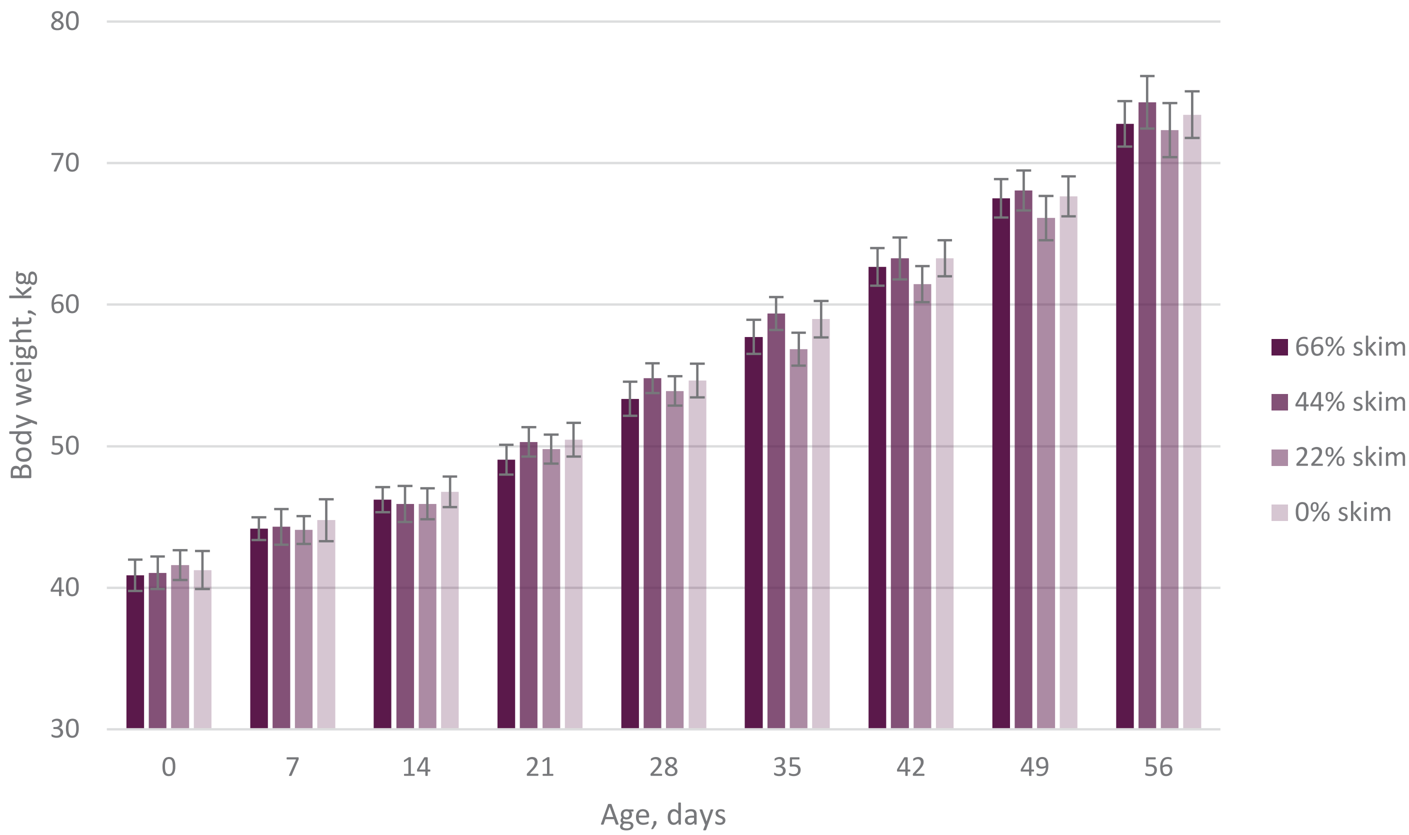
Table 4. Growth & health of calves fed milk replacers differing in sources of dairy protein (skim milk powder &/or whey protein concentrate) up to 10 weeks (Volac calf trial, AFBI, Hillsborough, Northern Ireland , 2019)

	Milk replacer composition				P-value
	66% skim	44% skim	22% skim	0% skim	
Number of calves	20	20	20	20	
Body weight, kg					
Birth	40.8	41.3	41.7	41.5	NS
Weaning, d56	73.2	74.5	71.9	73.5	NS
d70	89.1	89.4	86.3	87.0	NS
Daily live weight gain, kg/d					
d0-14	0.38	0.34	0.31	0.40	NS
d14-56	0.64	0.66	0.61	0.63	NS
d56-70	1.14	1.06	1.03	0.97	NS
Number of scour episodes[a]	0.75	0.63	0.54	0.39	NS
Number of respiratory episodes[b]	0.44	0.71	0.67	0.57	NS

Milk replacer (26% CP, 16% fat, mixed at 150g/L) fed at 5L/d (d5-10), 7L/d (d11-34), 5L/d d35-49, 2L/d (d49-55). Ad libitum calf starter & water available from birth, with the addition of chopped straw from day 56. [a]Scour episode defined as the number of sustained periods over which a calf has had scour (score > 2) for which it has received treatment. [b]Pneumonia episode was defined as a calf displaying symptom of pneumonia over a sustained period of time for which it received a treatment.

The performance of calves before and after weaning fed milk replacer containing whey protein concentrate (source: Volac Imunopro™ calf milk base) as the major source of dairy protein was equal to that of calves fed milk replacer with skim milk powder as the primary protein. Whey protein concentrate and skim were comparable sources of dairy protein in milk replacer diets for young calves fed up to 1050 g milk solids per day (Volac calf trial, AFBI, Hillsborough, Northern Ireland 2019).

Figure 4. Body weight of calves fed milk replacers differing in sources of dairy protein from birth to 8 weeks (Volac calf trial, AFBI, Hillsborough, Northern Ireland 2019)



Dairy Protein & Growth up to 6 Months:

The growth up to 6 months of age, and health, of Ayrshire bull calves fed diets in which skim milk powder was partly or completely replaced by whey products and wheat protein has been evaluated[5]. Calves (age 20 to 75 days) received one of three milk replacer diets differing in skim powder content: high skim (418 g SMP/kg dry matter); low skim (300 g SMP/kg dry matter); or no skim[5]. Partly or completely replacing skim milk powder with whey products early in life had no effect on growth until 6 months of age[5]. Furthermore, the use of the different milk replacers did not affect the incidence of diarrhoea, cough or bloat during the pre-weaning period: the mean percentage of feeding days that calves suffered bloat according to diet was high skim, 0.18%; low skim, 0.18%; and no skim, 0.18%[5].

Skim Milk Powder & Clot Formation:

Traditionally, skim-based milk replacers contained a defined skim content in order to qualify for subsidy, but since the withdrawal of subsidies in 2006, the level can vary and typically ranges from 20% to 50%. Whole milk and milk replacers containing a high level of casein protein (skim) will form a clot in the acid conditions of the abomasum as a result of the enzymes rennin and pepsin, acting upon the casein protein. A solid clot is retained in the abomasum[6] and this appears to have a beneficial effect on promoting nutrient digestibility[7]. If the casein does not clot, or forms only a weak curd, the clot will break up rapidly and undigested casein ('intact' casein) leaves the abomasum more quickly and passes into the small intestine[6]. Casein can only be digested in the duodenum after a good clot formation has taken place in the abomasum because the enzymes in the small intestine appear incapable of hydrolysing the specific peptide bonds acted on by rennin and pepsin. The relative strength of the clot formation will depend upon the inclusion level of skim (i.e. the level of casein protein) in the finished milk formula, as well as the manufacturing and processing methods used.

Inclusion Level of Skim: Reducing the level of skim in a milk formula has been shown to increase coagulation (clotting) time and reduce curd firmness (Table 5)[7]. Milk replacers were prepared that differed in the amount of skim milk powder – 67% SMP, 47% SMP, 33% SMP and 20% SMP[7]. As the level of skim milk powder was lowered, the clots were not formed as well, and curd firmness decreased from 50 g to 14 g (Table 5)[7]. Therefore, at a low-level inclusion in a milk formula, the casein protein in a skim-based milk replacer may not form a firm clot, causing the clots to break up and leave the abomasum more quickly[7].

Table 5. Effect of the level of skim milk powder in a milk replacer on clot / curd formation[7]

	67% SMP	47% SMP	33% SMP	20% SMP
Coagulation time (seconds)	34^b	45^b	73^a	69^a
Curd firmness (g)	50^a	30^b	21^{bc}	14^c

Milk replacer (23.5% CP, 20% fat) mixed at 14% solids. ^{abc}Means in row with different superscripts were significantly different (P<0.05)

Processing Temperature of Skim: Milk replacers containing low temperature treated skim milk produce a firm and elastic curd, whereas those containing high temperature treated skim form a flocculent and loose clot[6]. Subjecting skim milk powder to high temperatures (85°C) prior to spray-drying has been shown to reduce curd firmness, compared to heating to pre-drying temperatures of 60°C (low) or 74°C (medium) (Table 6)[6,8]. Holstein calves fed the high heat treatment skim milk powder had a reduced growth rate during the first 2 weeks of life, and the effect on growth was detectable at least until day 19 (Table 6)[8]. Furthermore, the incidence of diarrhoea was higher on the high heat treatment than on the medium or low heat treatment skim milks, although there were no differences in the incidence of respiratory infections (Table 6)[8]. In terms of calf health and performance, it appeared that the medium temperature treatment (74°C), which resulted in a curd firmness of 28g, was as good as the low temperature treatment (60°C) which provided a curd firmness of 64g[8].

Table 6. Effect of skim milk powder processing pre-drying temperature on curd formation & calf performance[8]

	Low (60°C)	Medium (74°C)	High (85°C)
Curd firmness (g)	64	28	7
Average daily gain d1-19 (g/d)	304^b	314^b	204^a
Diarrhoea (number of treatments per calf)	1.8^b	1.3^b	5.0^a

*Skim milk powder was heated to pre-drying temperature of either 60°C , 74°C or 85°C & held for 30 minutes before cooling. Milk replacer (mixed at 10% solids) fed at 2.0 kg liquid twice daily for first 3 days, then 5% of BW per feed for 2 days, followed by 6% of BW for next 22 days. abMeans in row with different superscripts were significantly different (P<0.05)

Abomasal Curd Formation:

It has been shown that the abomasum of some calves does not form a clot despite the ingestion of a clotting milk replacer – but the absence of abomasal curd formation had no significant impact on calf appearance, appetite, and vigour[10].

Twenty-nine Holstein Friesian and HF x Japanese black calves were fed a clotting milk replacer (mixed at 125 g/L; 24% crude protein, 16% fat, percentage of milk proteins, including skim milk and whey proteins was 66%) at 10% body weight twice daily[10]. Ultrasonography was used to distinguish the presence and absence of curd in the calves (aged 4 to 14 days) after feeding[10].

In 21 calves, a large curd mass was visualised, but abomasal curd was absent in 8 calves at 2 hours after feeding (the best time for evaluating curd formation is between 1–2 hours after feeding milk replacer, when a large curd mass can be imaged)[10]. The absence of curd formation did not have a significant impact on calf appearance, appetite and vigour (except for one non-curd-forming calf that exhibited wasting symptom) or on their blood parameters, including serum triglyceride, blood urea nitrogen and glucose concentrations[10].

The milk replacer had clotting properties (determined by an in vitro rennet coagulation test) and clotted in the abomasum of 21 calves – it was therefore not the cause for the absence of abomasal curd in the eight calves[10]. The absence of a curd in these calves was suggested to be due to their abomasal dysfunction for milk clotting[10]. It has previously been suggested that some calves are congenitally born with a low amount of curd-forming enzyme, resulting in no milk clotting[11].

Whey Protein & Immunoglobulins:

The whey fraction of colostrum and whole milk contains valuable bioactive proteins (e.g. immunoglobulins and lactoferrin) which are not present in casein. These functional proteins are essential to calf health (supporting defence mechanisms) and influence the growth and development of the young animal. However, care must be taken to minimise protein denaturation of these valuable bioactive proteins during manufacture due to the Maillard reaction, which is likely to occur when processing whey proteins. It has been shown that at processing temperatures of 85°C, over 60% of whey proteins were denatured within 30 minutes, whilst at 65°C only 15% of proteins were denatured[9].

Milk replacers based on whey powder, delactosed whey and / or whey protein concentrate will have varying levels of naturally occurring immunoglobulins as a result of the different manufacturing techniques used to process the liquid whey. High heat treatment (typically used to process whey powder, delactosed whey powders and food grade whey protein concentrate) destroys a large proportion of the naturally occurring immunoglobulins found in the whey fraction; therefore, finished milk powders that have undergone high heat treatment will likely have low levels of immunoglobulins.

The low temperature, ultrafiltration process used by Volac to process the liquid whey ensures that a high proportion of the naturally occurring immunoglobulins found in the whey fraction are retained in the finished milk formulas.

Good quality whey-based milk formulas result in calf growth at least as good as that achieved with high quality skim-based milk replacers. The presence of skim, and therefore the clotting effect of casein, is not the fundamental element of a milk formula influencing calf performance. If processed correctly, both skim and whey proteins are highly digestible and deliver good calf performance. But good nutrition and calf performance is linked to more than just the type of dairy protein in the finished milk formula. Important differences in amino acid profiles, fatty acid profiles, amount of lactose, important vitamins, minerals and trace elements, processing conditions and overall digestibility all contribute to calf performance.

Top Points:

1. Dairy ingredients are the main source of protein in milk replacers – these include both skim (casein) & whey
2. Skim & whey are both sources of milk protein
3. Calves can digest milk replacers with whey as the main dairy protein as efficiently as skim-based milk replacers, despite the whey proteins not forming a clot in the abomasum
4. Milk replacers with good quality skim or whey as the main dairy protein can both deliver good calf performance
5. The processing method of the dairy protein (both skim & whey) is fundamental for digestibility & calf performance
6. The level of skim (i.e. casein protein) in a finished milk formula will determine the clotting strength in the abomasum
7. Whey protein contains naturally occurring bioactive proteins (e.g. immunoglobulins & lactoferrin) that help to support the immune system, & influence the growth & development of the calf. Volac's Imunopro™ calf milk replacer base, contains these at higher levels.
8. Not all whey is the same - high quality concentrated whey protein such as Volac's Imunopro™ calf milk base, will give calves the best opportunity for growth & development

References

[1]Huber JT, Jacobson NK, Allen RS & Hartman PA (1961) Digestive enzyme activities in the young calf. Journal paper No. J-4053 of the Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa. Project No. 1324.

[2]Terosky TL, Heinrichs AJ & Wilson LL (1997) A comparison of milk protein sources in diets of calves up to eight weeks of age. Journal of Dairy Science 80:2977-2983

[3]Lammers BP, Heinrichs AJ & Aydin A (1998) The effect of whey protein concentrate or dried skim milk in milk replacer on calf performance and blood metabolites. Journal of Dairy Science 81:1940–1945

[4]Davis CL & Drackley JK (1978) The development, nutrition and management of the young calf. Iowa State University Press, Ames, Iowa, USA.

[5]Huuskonen A (2017) Effects of skim milk and whey-based milk replacers on feed intake and growth of dairy calves. Journal of Applied Animal Research 45:480-484

[6]Emmons DB & Lister EE (1976) Quality of protein in milk replacers for young calves I. Factors affecting in vitro curd formation by rennet (chymosin, rennin) from reconstituted skim milk powder. Canadian Journal of Animal Science 56:317-25

[7]Jenkins KJ (1982) Effect of Acid-Precipitated Casein in Calf Milk Replacer on Rennet Clot. Journal of Dairy Science 65:1652-1654

[8]Lister EE & Emmons DB (1976) Quality of protein in milk replacers for young calves II. Effects of heat treatment of skim milk powder and fat levels on calf growth, feed intake and nitrogen balance. Canadian Journal of Animal Science 56:327-333

[9]Richert SH, Morr CV & Cooney CM (1974) Effect of heat and other factors upon foaming properties of whey protein concentrates Journal of Food Science 39

[10]Miyazaki T, Miyazaki M, Yasuda J, Okada K (2010) No abomasal curd formation in pre-ruminant calves after ingestion of a clotting milk replacer. The Veterinary Journal 183:205–209

[11]Gregory N (2003) Effect of enhancing curd formation during the first colostrum feed on absorption of gamma glutamyl transferase by newborn calves. Australian Veterinary Journal 81:549–552

Abbreviations

ADG Average daily gain
BW Body weight
CP Crude protein
DM Dry matter
DMI Dry matter intake
DSM Dry skim milk
SMP Skim milk powder
WPC Whey protein concentrate

Feed for Growth promotes efficient and sustainable youngstock rearing practices. Our high-quality, nutritional solutions are scientifically formulated to ensure optimal rumen development

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